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FOR

COMMUNICATION WITH CURRENT DETECTION

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COMMUNICATION WITH CURRENT DETECTION

FIELD OF THE INVENTION

[0001] This invention relates to communication systems in general, and more specifically to operation of a communication system using current detection.

BACKGROUND OF THE INVENTION

[0002] Communication using current detection has been used in current loop communications technology for many years. For example, in the 1960's, military teleprinters used 60 milliamp current loops to communicate. In later periods, 20 milliamp current loops became more prevalent. In a conventional current loop, a current source provides a specified current on a loop. A signal is transmitted on the current loop by opening and shutting a switch within the loop. A receiver utilizes a current detector to receive the transmitted signal. Current loops have the advantage that they allow longer communications paths than certain other technologies. Converters may be used to convert signals to, for example, RS-232 format for communication with computers.

[0003] Figure 1 illustrates a full-duplex current loop. In this instance, both parties to the communication can send and receive a signal simultaneously. In this illustration, first participant **100** and second participant **110** communicate with each other. First participant **100** in Figure 1 is an "active" participant because first participant **100** provides the current sources **140** and **170** for the current loop system. Second participant **110** is a "passive" participant. In such a conventional full-duplex current loop, it is possible for either or both participants to be active, depending on the design of the system.

[0004] The system shown in Figure 1 includes two circuit loops, a first circuit loop **120** and a second circuit loop **130**. In first circuit loop **120**, first participant **100** is the receiving participant and second participant **110** is the transmitting participant. In second circuit loop **130**, first participant **100** is the transmitting participant and second participant **110** is the receiving participant.

[0005] Within first circuit loop **120**, current source **140** produces a current through the circuit loop. Second participant **110** transmits a signal on first circuit loop **120** by opening or closing switch **150**. First participant **100** then receives the signal transmitted by second participant **110** by detecting the current in first loop **110** using current detector **160**. Similarly, within second circuit loop **130**, current source **170** produces a current through the circuit loop. First participant **100** transmits a signal on second circuit loop **130** by opening or closing switch **180**. Second participant **110** then receives the signal transmitted by first participant **100** by detecting the current in first loop **130** using current detector **190**.

[0006] Figure 2 illustrates a simplex, or half-duplex, current loop. In this instance, only one party to the communication can send a message at any time. In this illustration, first participant **200** and second participant **210** communicate with each other. First participant **200** in Figure 2 is the "active" participant because first participant **200** provides the current source **230** for the current loop system. Second participant **210** is a "passive" participant. In a conventional simplex current loop, it is possible for either participant to be the active participant depending on the design of the system. The system shown in Figure 2 includes a single circuit loop **220**. In the circuit loop **220**, first participant **200** and second participant **210** alternate as the transmitting participant and

the receiving participant.

[0007] Within circuit loop **220**, current source **230** produces a current through circuit loop **220**. In one instance, first participant **200** transmits a signal on circuit loop **220** by opening or closing switch **240**. Second participant **210** then receives the signal transmitted by first participant **200** by detecting the current in circuit loop **220** using current detector **270**. In a second instance, second participant **210** transmits a signal on circuit loop **220** by opening or closing switch **250**. First participant **200** then receives the signal transmitted by second participant **210** by detecting the current in circuit loop **220** using current detector **260**.

[0008] The conventional current loops illustrated in Figures 1 and 2 have characteristics that limit the usefulness of these communications systems. Among other issues, the conventional transmission of a signal by opening and closing a circuit connection creates an unbalanced transmission signal that results in significant noise problems. While communications over relatively long distances are possible with a current loop system, the noise that is present on a conventional current loop system limits the speed that can be realized by the system, and thereby limits the usefulness of the system in modern high-speed communications.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The appended claims set forth the features of the invention with particularity. The invention, together with its advantages, may be best understood from the following detailed description taken in conjunction with the accompanying drawings, of which:

[0010] Figure 1 illustrates a conventional full-duplex current loop;

[0011] Figure 2 illustrates a conventional simplex (or half-duplex) current loop;

[0012] Figure 3 is a diagram illustrating a transmitter under one embodiment;

[0013] Figure 4 is a diagram illustrating a receiver according to one embodiment;

[0014] Figure 5 illustrates embodiments of a transmitter coupling and a receiver coupling;

[0015] Figure 6 illustrates a signal that is transmitted according to an embodiment in which a sine wave generator produces a DC offset voltage; and

[0016] Figure 7 illustrates a signal that is transmitted according to an embodiment in which a sine wave generator does not produce a DC offset voltage.

DETAILED DESCRIPTION

[0017] A method and apparatus are described for providing a communication system using current detection.

[0018] In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without some of these specific details. In other instances, well-known structures and devices are shown in block diagram form.

[0019] The present invention includes various processes, which will be described below. The processes of the present invention may be performed by hardware components or may be embodied in machine-executable instructions, which may be used to cause a general-purpose or special-purpose processor or logic circuits programmed with the instructions to perform the processes. Alternatively, the processes may be performed by a combination of hardware and software.

[0020] This application describes a method and apparatus for transmitting a balanced signal and detecting the signal using current detection. Under one embodiment, the transmission system may utilize a standard twisted pair cable for the transmission medium. According to one embodiment, the transmission line is a standard 100-ohm impedance cable. According to a further embodiment, a transmitter generates a signal by switching between two power sources, thereby creating a current signal. The transmitter creates a signal in which a positive domain signal and a negative domain signal are generated. The transmission is balanced and the positive and negative domain symmetric signals cancel or counter each other in the radio frequency domain. The system assists in

the rejection of noise because of the balanced signal arrangement. As long as a signal on the transmission line is balanced, crosstalk on the transmission line is thereby largely eliminated. According to an embodiment, the signal on the transmission line never passes through the zero (0) volts ground reference and the current never changes direction on the separate wires of the transmission line. According to this embodiment, the detection system equalizes the two transmission channels and rejects the common mode noise. After the noise is cancelled, the residual signal is then amplified to a minimum 5-decibel signal to noise ratio (SNR) level. According to one embodiment, the signal is delivered into a high-speed current detector that converts the current signal into a TTL (transistor-transistor logic), ECL (emitter-coupled logic), PECL (pseudo emitter-coupled logic), or other type of signal for digital interfacing. In an embodiment, the ability to reduce the impact of noise on the transmission line allows increased speed of operation. According to a particular embodiment, using common forward error correction (FEC) techniques such as Reed Solomon, Turbo, or Viterbi codes allows for additional information throughput in a system.

[0021] According to one embodiment, the transmitter includes a direct current power source and a sinusoidal power source, such as a sine wave signal generator. In this embodiment, the transmitter transmits a signal on the transmission line by switching between the DC power source and the combination of the DC power source and the sine wave signal. The DC power source establishes the base voltage level of the signal. When switched, the system switches to the sum of the DC power source and the sine wave signal. According to one embodiment, the sine wave signal contains a DC offset

such that the resulting sinusoid level is always above the base voltage level in the positive domain and below the base voltage level in the negative domain.

[0022] According to another embodiment, the sine wave signal contains no DC offset such that the base level is the x-axis of the resulting sinusoid. According to one embodiment, a low frequency (between 400 hertz and 3300 hertz) sinusoidal wave is used when transmitting through load coils. The advantage of the low frequency sine wave is that the load coils help maintain the power spectrum on the low frequency over distance to counter the attenuation of the transmission line, which enhances the transmission of the signal over longer distances. According to one embodiment of the invention, the voltage levels of the power sources are such that the current flowing through the transmission line does not change in direction. In this transmission system, the current differential of the transmission is maintained as the signal is attenuated over extended wire distances.

[0023] According to an embodiment, each load coil on the transmission line increases the relative low frequency spectral power on the line by approximately 8.5 dB, if the load coils are spaced correctly. Each load coil normally has no effect on the current level, with the current into the load coil being substantially the same as the current out of the load coil. However, a gain in the voltage provided by the load coil has a corresponding effect on current. The resulting effect of the transmission technique under an embodiment is that signal transmission is possible over extended distances at high speeds.

[0024] According to an embodiment, a receiver coupled to the transmission line includes a current detector that detects the transmitted signal. Under one embodiment,

the receiver detects the signal by sensing changes in the magnetic field generated by the current flowing through the transmission line. In an embodiment of the communications system, the current produced always travels in one direction, but the current detector senses an apparent current direction change. According to an embodiment of the invention, a balanced signal is detected using a pair of current detectors.

[0025] According to one embodiment, the receiver utilizes a detector that is capable of detecting a current change in which a current of 7-10 milliamps flowing in one direction in a circuit changes to a current of 7-10 milliamps flowing in the other direction. According to one embodiment, the actual change in current in a transmission line could be much smaller than the change in current that the current detector can sense, but this actual change in current may be amplified, through use of a technology such as current feedback amplifiers, to a level that is high enough to be sensed by the current detector. Under one embodiment, the current detector included in the receiver is a magnetic field sensor, such as those produced by Nonvolatile Electronics, Inc. (NVE) of Eden Prairie, Minnesota. Under a particular embodiment, a magnetic field sensor contains giant magnetoresistive (GMR) materials in its construction. Using common forward error correction technology such as Reed Solomon, Turbo or Viterbi type codes will provide additional bandwidth increases.

[0026] Figure 3 is an illustration of a transmitter according to one embodiment of the invention. In this embodiment, a digital signal **300** is transmitted. Digital signal **300** is used to control a positive domain switch **305** and a negative domain switch **310**. Positive domain switch **305** switches between the positive voltage supplied by DC voltage source **315**, designated as V_S+ in Figure 3, and the sum of DC voltage source **315**

and sine wave generator **320**, designated as V_{SS}+ in Figure 3. Negative domain switch **310** switches between the negative voltage supplied by DC voltage source **315**, designated as V_S - inb Figure 3, and the sum of DC voltage source **315** and sine wave generator **320**, designated as V_{SS} - in Figure 3. According to one embodiment, the signal provided by sine wave generator **320** to negative domain switch **310** is 180 degrees out of phase with the signal provided to positive domain switch **305**. In Figure 3, positive domain switch **305** is generating the positive domain image of the transmitted signal and switch **310** is generating the negative domain image of the transmitted signal. While the diagram contained in Figure 3 conceptually shows DC voltage source **315** and sine wave generator **320** in multiple locations for simplicity, according to a particular embodiment the transmitter contains a single DC voltage source and a single sine wave generator.

[0027] In Figure 3, amplifier **330** amplifies the positive domain signal image generated by switch **305** and amplifier **335** amplifies the negative domain signal image generated by switch **310**. The positive and negative domain images of the signal then pass through coupler **340**. The signal that is then transmitted on the transmission line is comprised of positive domain signal image T_X + **345** and negative signal domain image T_X - **350**.

[0028] In the embodiment of the transmitter shown in Figure 3, the loop formed by the transmission line is closed at all times when the system is active and thus there is always a current flowing through the transmission line. This contrasts with the conventional current loops shown in Figures 1 and 2, in which a signal is generated by opening and closing the circuit. Under a particular embodiment, an active transmission line is indicated when current flows through the line and an inactive circuit is indicated

when no current is flowing through the line. In this way, according to a particular embodiment a device may detect whether a transmission line is active by detecting whether any current is flowing through the transmission line.

[0029] Figure 4 illustrates an embodiment of a receiver utilizing current detection. In Figure 4, a positive domain image of a received signal R_X + **400** and a negative domain image of the received signal R_X - **405** are received. The received signal is passed through coupler **410**. The positive domain image of the signal is amplified by amplifier **415** and the negative domain image of the signal is amplified by amplifier **420**. According to one embodiment, amplifiers **415** and **420** are comprised of two or more amplification stages. The amplified signal is then detected by current detectors **425** and **430**. According to one embodiment, current detectors **425** and **430** each utilize both the positive and negative images of the signal to detect the current changes. The resulting data **435** is then produced from the outputs of the current detectors **425** and **430**.

[0030] In one embodiment of the invention, a transceiver includes both a transmitter that generates a balanced current signal and a receiver that detects a signal using current detection. An example of the transceiver would contain the elements shown in Figure 3 and the elements shown in Figure 4.

[0031] According to one embodiment, the coupling of a transmitter or receiver to the transmission line is shown in Figure 5. In the transmitter coupling **500**, variable resistor **510** is in parallel with the series combination of variable resistor **515** and variable resistor **520**. According to this embodiment, the connection between variable resistor **515** and variable resistor **520** is connected to ground **525**. Signal T_X **530** is transmitted to a

transmission line through the transmitter coupling **500**. Under this embodiment, a transmitter is interfaced with a transmission line without the use of transformers.

[0032] Similarly, the receiver coupling **505** shown in Figure 5 is comprised of variable resistor **555** in parallel with the series combination of variable resistor **540** and variable resistor **545**. The connection between variable resistor **540** and variable resistor **545** is connected to ground **550**. Signal R_X **535** is received from a transmission line through the receiver coupling **505**. According to this embodiment, a receiver is also interfaced with a transmission line without the use of transformers.

[0033] According to an embodiment of the invention, a receiver is impedance matched by placing two resistors of the same value in series, with one lead of one resistor being connected to one of the two wires in a transmission line and one lead of the other resistor being connected to the other transmission line wire. According to this embodiment, the connection between the two resistors is connected to ground. An example of impedance matching is shown in Figure 5. Resistor **560** is in series with resistor **565**, with the connection point between resistors **560** and **565** being connected to ground **570**. In the example shown in Figure 5, resistor **560** and resistor **565** are 50-ohm resistors to form a 100-ohm resistance to match the impedance of a 100-ohm transmission line.

[0034] Figure 6 contains a conceptual graph of a signal generated on a transmission line under one embodiment. In Figure 6, a DC voltage source provides a positive base voltage level **605** above zero voltage level **600** and a negative base voltage level **610** below zero voltage level **600**. A sine wave generator generates a sinusoidal waveform **615** for the positive domain image of the transmitted signal and a sinusoidal

waveform **620** for the negative domain image of the transmitted signal, where sinusoidal waveform **620** is inverted, or shifted 180 degrees in phase, from sinusoidal waveform **615**. In Figure 6, the sine wave generator has generated a positive DC voltage offset **625** and a negative DC voltage offset **630**. With the given voltage offsets **625** and **630**, the positive domain image of the signal **635** is in the form of pulses rising above the positive base voltage level **605** to the level of sinusoidal waveform **615**, and the negative domain image of the signal **640** is in the form of pulses falling below the negative base voltage level **610** to the level of sinusoidal waveform **620**.

[0035] The DC voltage offset shown in Figure 6 is not necessary to the operation of a transmitter or receiver, and other embodiments may contain other voltage levels or may contain no DC voltage offset. For example, Figure 7 contains a conceptual graph of a signal transmitted on a transmission line under a particular embodiment in which no DC voltage offset is present. In Figure 7, a DC voltage source provides a positive base voltage level **705** above zero voltage level **700** and a negative base voltage level **710** below zero voltage level **700**. A sine wave generator generates a sinusoidal waveform **715** for the positive domain image of the transmitted signal and an inverted sinusoidal waveform **720** for the negative domain image of the transmitted signal. Without any DC voltage offset, the x-axes of sinusoidal waveforms **715** and **720** are positive base voltage level **705** and negative base voltage level **710**. In the embodiment shown in Figure 7, the positive domain image of the signal **725** is in the form of pulses above and below the positive base voltage level **705** to the sinusoidal waveform **715**, and the negative domain image of the signal **730** is in the form of pulses above and below negative base voltage level **710** to the sinusoidal waveform **720**.

[0036] In the foregoing specification, the invention has been described with reference to specific embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.